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FOR

<u>MICROPIN HEAT EXCHANGER</u>

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MICROPIN HEAT EXCHANGER

TECHNICAL FIELD

[0001] The invention generally relates to cooling electronic apparatuses and systems, and in particular, but not exclusively relates to micro-cooling technology.

BACKGROUND INFORMATION

[0002] As electronic devices become more powerful and smaller (i.e., more densely packed), the power consumed by these electronic devices can result in a large amount of generated heat. The heat generated by these electronic devices may be detrimental to the operation of the electronic devices. Accordingly, a common concern associated with electronic components is heat removal.

[0003] For example, an electronic device may include an integrated circuit (IC) die. A thermal solution may be thermally coupled to the IC die to facilitate dissipation of heat from the IC die. Commonly, the thermal solution may be in the form of a heat sink having a number of fins or channels (i.e., a passive solution). As air passes by the fins or channels, heat may be transferred from the IC die to the surrounding air via the fins or channels. Alternatively, an active solution may be in the form of forced fluid across the fins or channels. However, utilizing fins or channels do not provide efficient and uniform removal of heat from the IC die due to various effects such as, but not limited to, variations of heat generation from different areas on the IC die.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The various embodiments of the invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings, in which the like references indicate similar elements and in which:

[0005] **Figures 1a-1b** illustrate an apparatus having a micropin thermal solution, in accordance with one embodiment of the invention;

[0006] **Figure 2** illustrate a method of forming micropins, in accordance with one embodiment;

[0007] **Figure 3** illustrates an apparatus having a micropin thermal solution, in accordance with an alternate embodiment;

[0008] **Figure 4** illustrates an apparatus having a micropin thermal solution, in accordance with another embodiment;

[0009] **Figure 5** illustrates an apparatus having a micropin thermal solution, in accordance with another embodiment;

[0010] **Figures 6a-6b** illustrate an apparatus having a micropin thermal solution, in accordance with various embodiments; and

[0011] **Figures 7a-7b** illustrate a micropin thermal solution, in accordance with various embodiments.

DETAILED DESCRIPTION

[0012] In various embodiments, an apparatus including a micropin thermal solution is described. In the following description, various embodiments will be described. However, one skilled in the relevant art will recognize that the various embodiments may be practiced without one or more of the specific details, or with other methods, materials, components, etc. In other instances, well-known structures, materials, or operations are not shown or described in detail to avoid obscuring aspects of various embodiments of the invention. Similarly, for purposes of explanation, specific numbers, materials and configurations are set forth in order to provide a thorough understanding of the invention. Nevertheless, the invention may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order not to obscure the invention. Furthermore, it is understood that the various embodiments shown in the figures are illustrative representations and are not necessarily drawn to scale.

[0013] Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, material, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment or invention. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments.

[0014] Various operations will be described as multiple discrete operations in turn, in a manner that is most helpful in understanding the invention. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

[0015] **Figures 1a-1b** illustrate an apparatus having a micropin thermal solution, in accordance with one embodiment of the invention. Illustrated in **Fig. 1a** is a side like view of an apparatus **100**. In **Fig. 1a**, the apparatus **100** includes a substrate **102** and a number of micropins **104**. **Fig. 1b** illustrates a top like view of the apparatus **100**. Accordingly, as shown in **Fig. 1b**, the micropins **104** are arranged in a pixel like pattern over the substrate **102**, in accordance with various embodiments of the invention.

[0016] Referring to **Fig. 1b**, the micropins **104** may be arranged to provide a predetermined space between the micropins **104**. As will be described in more detail, the predetermined space may be based at least in part on the material that flows through the space such as, but not limited to water in liquid form. Further, the micropins **104** arranged in the pixel like pattern shown in **Fig. 1b** facilitates flow of material in all directions such as, but not limited to, at least two directions (e.g., the x-direction and the y-direction) as viewed in **Fig. 1b**.

[0017] In the illustrated embodiment shown in **Fig. 1a**, the micropins **104** may be formed from the substrate **102**. That is, various etching methods may be utilized to form the micropins **104** from the substrate **102** such as, but not limited to, deep reactive ion etching (DRIE), wet etching, micromachining, and the like. Accordingly, the micropins **104** may be made of a semiconductor material, such as but not limited to silicon.

Alternatively, the micropins **104** may be formed and disposed on the substrate **102**. That is, the micropins **104** may be made of a variety of materials and methods such as, but not limited to, metals (e.g., copper) and micromachining methods, and subsequently disposed on the substrate. Additionally, the substrate **102** may be an integrated circuit (IC) die. Alternatively, the substrate **102** may be thermally coupled to an IC die.

[0018] The thermal energy (i.e., heat) from the substrate may be transferred to the micropins **104**. Because in one embodiment, the micropins **104** are formed on the substrate **102**, the micropins **104** may be thermally coupled to the IC die, and in turn, the micropins **104** facilitate transfer of heat to the material in substantial contact with the micropins **104**. Alternatively, the micropins **104** may be thermally coupled to the substrate, which in turn, may be thermally coupled to an IC die. That is, effectively, the micropins **104** are thermally coupled to the IC die.

[0019] **Figure 2** illustrate a method of forming micropins, in accordance with one embodiment. Shown in **Fig. 2** is a side like view of a substrate **202**. The substrate **202** may be made of a suitable material to facilitate heat transfer such as, but not limited to, silicon based material, and a metal based material (e.g., silicon, copper, etc.). Various etching methods may be applied to the substrate **202** such as, but not limited to, DRIE, wet etching, micromachining, and so forth. As a result of the etching process, a number of micropins **204** may be formed from the substrate **202**.

[0020] In the illustrated embodiment, formed along with the micropins **204** may be a side wall **206**. As will be described in further detail, in various embodiments, the side wall **206** facilitates substantial enclosure of the micropins **204** within a device to

facilitate heat removal from an integrated circuit (IC) die, and a cover may further facilitate the enclosure of the micropins **204**.

[0021] **Figure 3** illustrates an apparatus having a micropin thermal solution, in accordance with an alternate embodiment. In **Fig. 3**, a side like view is illustrated of an apparatus **300**. The apparatus **300** includes a substrate **302** and a number of micropins **304** similar to the apparatus **100** shown in **Fig. 1a-1b**. However, illustrated in **Fig. 3**, the apparatus **300** includes an interface layer **306** disposed between the micropins **304** and the substrate **302**.

[0022] In accordance with one embodiment, the interface layer **306** may be of a material to provide structural support for the micropins **304** and facilitate thermal coupling such as, but not limited to, a diamond film. As previously described, the micropins **304** may be made of a semiconductor material, and accordingly, the interface layer may provide structural support for the micropins **304** and facilitate thermal coupling (i.e., heat transfer) from the substrate **302** to the micropins **304**. Here again, the substrate may be an IC die or a substrate that may be thermally coupled to an IC die.

[0023] In one embodiment, the interface layer **306** may be made of a solderable material having various thermal properties such as, but not limited to, copper (Cu), gold (Au), nickel (Ni), aluminum (Al), titanium (Ti), tantalum (Ta), silver (Ag), Platinum (Pt), and any combination thereof. Accordingly, in one embodiment, the micropins **304** may be made of a metal material such as, but not limited to, copper.

[0024] Continuing to refer to **Fig. 3**, it should be appreciated by those skilled in the relevant art that in addition to the interface material **306**, various adhesive materials (not shown) may be utilized between the micropins **304** and the substrate **302**.

[0025] **Figure 4** illustrates an apparatus having a micropin thermal solution, in accordance with another embodiment. Illustrated in **Fig. 4**, is a cross-sectional type view of an apparatus having a device **400**. The device **400** includes substrate **402** and a number of micropins **404**. As shown in the embodiment, the substrate **402** provides a bottom of the device **400**. Additionally, the device **400** includes a wall **406** that substantially surround the micropins **404**. Further, a cover **408** disposed over the micropins **404** results in the micropins **404** being substantially enclosed in the device **400**.

[0026] The micropins **404** and the side wall **406** may both be formed from the substrate **402** as previously described in **Fig. 2**. The cover **408** may be attached to the micropins **404** by various attachment methods such as but not limited to, solder, adhesive, anodic bonding, thermal compression bonding, and so forth. Additionally, the cover may be made of various materials such as, but not limited to, acrylic based material (e.g., plexiglas® from Rohm & Haas Corporation of Philadelphia, PA).

[0027] The device **400** has an inlet **410** and an outlet **412**. As will be described in detail, the inlet **410** and the outlet **412** facilitates flow of material through the micropins **404**. Additionally, in **Fig. 4**, an interface layer **414** is shown between the cover **406** and the micropins **404**. The interface layer **414** may be any type of layer that facilitates a seal between the cover **406** and the micropins **404**. Accordingly, the interface layer **414** may be of a solderable material, adhesive material, or any combination thereof.

[0028] **Figure 5** illustrates an apparatus having a micropin thermal solution, in accordance with another embodiment. Illustrated in **Fig. 5**, is a cross-sectional type view of an apparatus having a device **500**. The device **500** includes a substrate **502** and a number of micropins **504**. As shown in the embodiment, the substrate **502** provides a bottom of the device **500**. Additionally, the device **500** includes a wall **506** that substantially surround the micropins **504** similar to the device **400** shown in **Fig. 4**. However, in the embodiment illustrated in **Fig. 5**, a cover **508** has the micropins **504** formed on the cover **508**. Here again, the micropins **504** are substantially enclosed in the device **500**.

[0029] The device **500** has an inlet **510** and an outlet **512**. As will be described in detail, the inlet **510** and the outlet **512** facilitates flow of material through the micropins **504**. Additionally, in **Fig. 5**, an interface layer **514** is shown between the micropins **504** and the substrate **502**. The interface layer **514** may be any type of layer that facilitates a seal between the micropins **504** and the substrate **502**. Accordingly, the interface layer **514** may be of a solderable material, adhesive material, or any combination thereof.

[0030] As previously alluded to, the cover **508** having the micropins **504** may be of any material such as, but not limited to, silicon and metal. Additionally, in the illustrate embodiment, the cover **508**, having the micropins **504**, may be formed as described in **Fig. 2** (i.e., various etching methods).

[0031] In **Figs. 1-5**, the number of micropins may be arranged in the pixel like pattern as shown in **Fig. 1b**. Additionally, as previously described, the substrate may be an IC die. Alternatively, the substrate may be a substrate that is thermally coupled to

an IC die. It should be appreciated by those skilled in the art that the substrate and the micropins may be thermally coupled via various thermal interface materials (TIMs).

[0032] In one embodiment, each of the micropins may have the following approximate overall dimensions: 50 microns in width, 50 microns in thickness, and a height of 300 microns. Referring to **Fig. 1b**, in one example arrangement, the pitch may be approximately 50 microns and the substrate may have approximate dimensions of 1 centimeter by 1 centimeter. Accordingly, in the example arrangement, the number of pins may be approximately 10000 micropins.

[0033] Various thermal and mechanical considerations may have an effect on the material utilized for the interface layer and/or the adhesive layer (not shown). For example, thermal considerations may include the coefficient of thermal expansion (CTE) considerations, thermal conductivity, and the like. Some mechanical considerations may include toughness, strength, and the like. Further, in various embodiments, the micropins **104** may be of any type of shape such as, but not limited to, a primitive geometric shape and a complex geometric shape. For example the micropins **104** may be cylindrical, rectangular, etc. including shapes without symmetry.

[0034] **Figures 6a-6b** illustrate an apparatus having a micropin thermal solution, in accordance with various embodiments. Illustrated in **Fig. 6a** is a cross-sectional type view of an electronic system **600** having apparatuses that may be representative of the apparatuses shown in **Figs. 1-5** having micropins **602**. The electronic system **600** is shown having the micropins **602** disposed directly on top of an IC die **604** (i.e., the micropins **602** are thermally coupled to the IC die **604**). The IC die **604** may be electrically coupled to a substrate **606** via a number of solder bumps **608**. The

substrate **606** may be electrically coupled to a wiring board **610** via solder balls **612**. Accordingly, heat generated by the IC die **604** may be transferred to the micropins **602**.

[0035] Turning now to **Fig. 6b**, shown in **Fig. 6b** is a cross-sectional type view of an electronic system **620** having apparatus **620** that may be representative of the apparatuses shown in **Figs. 1-5** having micropins **602**. In **Fig. 6b**, the micropins **602** are shown thermally coupled to a substrate **622**, which in turn may be thermally coupled to an IC die **624**. Shown in **Fig. 6b**, an interface layer **626** may be disposed between the substrate **622** and the IC die **624**. As previously alluded to, the interface layer **626** may be a TIM that facilitates thermal coupling of the substrate **622** with the IC die **626**, thereby facilitating heat transfer from the IC die **626** to the micropins **602**.

[0036] Continuing to refer to **Fig. 6b**, the apparatus **620** is shown thermally coupled to the IC die **622**. The IC die may be electrically coupled to the substrate **606** via solder bumps **608**. The substrate **606** may be electrically coupled to the wiring board **610** via solder balls **612**. Here again, the heat generated by the IC die **622** may be transferred to the micropins **602** because effectively, the micropins **602** may be thermally coupled to the IC die **622**.

[0037] Shown in **Figs. 6a-6b**, the micropins **602** are substantially enclosed in the device **600 & 620**. However, as described previously, the micropins **602** need not be substantially enclosed (see **Figs. 1-3**). Additionally, in various embodiments, the wiring board **610** may have various devices electrically coupled to it such as, but not limited to a memory device (e.g., a flash memory device).

[0038] **Figures 7a-7b** illustrate a micropin thermal solution, in accordance with various embodiments. Illustrated in **Fig. 7a** is a top like view of an apparatus **700** that

may be representative of the apparatuses shown in **Figs. 4-6**. Accordingly, the apparatus has the number of micropins **404 & 504** substantially enclosed the device **400 & 500**. Additionally, the device **400 & 500** has the inlet **410 & 510** and the outlet **412 & 512**. As shown, the micropins **404 & 504** are arranged in the pixel like pattern as previously described.

[0039] Referring now to **Fig. 7b**, the apparatus **700** may be included in a heat exchange system. Shown in **Fig. 7b** is a simplified view of a heat exchange system **720**. The heat exchange system **720** includes the apparatus **700**, a pump **722**, and a heat exchanger **724**.

[0040] As previously described, the apparatus **700** has the inlet **410 & 510** and the outlet **412 & 512**. The pump **722** has an inlet **726** and an outlet **728**. The heat exchanger **724** has an inlet **730** and an outlet **732**. As shown in **Fig. 7**, the outlet of the pump **728** may be coupled to the inlet **410 & 510** of the apparatus **700** (i.e., device) to facilitate transfer of material (i.e., material transferably coupled). The inlet **726** of the pump **728** may be material transferably coupled to the outlet **732** of the heat exchanger **724**. The outlet **412 & 512** may be material transferably coupled to the inlet **730** of the heat exchanger **724**.

[0041] As shown in **Fig. 7b**, a material such as, but not limited to, liquid water may be pumped to the apparatus **700**. The micropins, being thermally coupled to an IC die, facilitate heat transfer to the liquid water. As more heat is transferred to the liquid water, the liquid water may become steam. Further, as varying areas of the IC die generate varying amounts of heat, utilization of micropins and the manner in which the micropins are arranged facilitates uniform cooling of the IC die.

[0042] The pump **722** and the heat exchanger **724** may be any type of pump and heat exchanger such as, but not limited to, an electroosmotic pump. Additionally, the material utilized for the heat exchange system **720** may be any material such as, but not limited to, fluid, gas, and nanoparticles.

[0043] In the illustrated embodiment of **Fig. 7b**, the pump **722** provides material to the apparatus **700**. The apparatus facilitates removal of heat from an IC die, as previously described. The heat exchanger **724** receives the heated material and removes the heat to another heat sink (not shown). It should be appreciated that in order not to obscure the embodiments of the invention, various components of the heat exchange system **720** are not shown. For example, there may various valves, seals, and so forth.

[0044] Having described and illustrated the principles of the invention with reference to illustrated embodiments, it will be recognized that the illustrated embodiments can be modified in arrangement and detail without departing from such principles. And, though the foregoing discussion has focused on particular embodiments, other configurations are contemplated. In particular, even though expressions such as "in one embodiment," "in another embodiment," or the like are used herein, these phrases are meant to generally reference embodiment possibilities, and are not intended to limit the invention to particular embodiment configurations. As used herein, these terms may reference the same or different embodiments that are combinable into other embodiments.

[0045] Thus, it can be seen from the above descriptions, a novel apparatus including a micropin thermal solution has been described.

[0046] The above description of illustrated embodiments of the invention, including what is described in the Abstract, is not intended to be exhaustive or to limit the invention to the precise forms disclosed. While specific embodiments of, and examples for, the invention are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. Thus, the description is to be regarded as illustrative instead of restrictive on the invention.

[0047] Consequently, in view of the wide variety of permutations to the embodiments described herein, this detailed description is intended to be illustrative only, and should not be taken as limiting the scope of the invention. What is claimed as the invention, therefore, is all such modifications as may come within the scope and spirit of the following claims and equivalents thereto.